DTU Library

Modelling of heating sector in Denmark with focus on local externalities

Zvingilaite, Erika

Publication date:
2009

Modelling of heating sector in Denmark with focus on local externalities

PhD candidate Erika Zvingilaite*
Systems Analysis Division
Risø National Laboratory for Sustainable Energy
Technical University of Denmark – DTU
e–mail: erzv@risoe.dtu.dk

ABSTRACT

The paper focuses on finding the efficient strategies for energy use in the Danish heating sector in order to reduce air pollution, consequent impacts on human health and the costs for the society. The task is to clarify the connections between the heat use, heat production, air pollution, health and the economy by including energy efficiency improvements in buildings and local externalities into an energy system optimisation model.

Reducing end-use energy demand in general reduces the environmental impact of the whole energy system. At the same time the environmental impacts depend on the fuels and technologies used for covering energy demand. When striving to halt climate change by reducing CO_2 emissions, both decreasing the amount of energy consumed and switching to renewable energy production are comparable means to reach the goal. Whereas, when the focus is on reducing local external effects, such as negative impacts on health, from energy consumption and production, local air pollutants ($PM_{2,5}$, SO_2 and NO_x) are in focus. Energy efficiency has also potentials in reducing the amount of these pollutants, while technology and fuel choices have high influence on local air pollution. Besides, for local external effects not only the type and amount of pollutants is important – the location height and even time of pollution release are also essential. This means, that pollution from energy production with low stack in densely populated areas have worse local effects than centralised production of the same type, with rural location and high emission stack. Hence environmental benefits of energy savings and clean energy technologies will be larger when replacing energy production with worst local impacts due to location and/or emission rates.

The regional energy system model Balmorel is used to study the possibilities to reduce local air pollution and negative effects on human health from heating sector in Denmark when values of local externalities are included in the model. The included monetary values of damage to human health are expressed per unit of pollutant and differ based on the size and the location of a heat production technology.

* Corresponding author

DISTRICT HEATING IN DENMARK AND LOCAL EXTERNALITIES :

The results of several studies have shown evidence that long- as well as short-term exposure to increased concentrations of classical air pollutants from energy production (SO_2, $PM_{2,5}$, NO_x) cause health effects – mortality and morbidity (Hertel et al., 2001).

The Danish heating sector contributes to local air pollution by three sources: district heating cogeneration or heat only plants; individual heating devices, using electricity or various fuels, such as natural gas, oil or biomass; and wood combustion in fireplaces. Heat demand for space heating in Denmark is around 213PJ annually which corresponds to one quarter of annual primary energy consumption in the country (Danish Energy Authority (DEA, 2007)). The average heating season is long – approximately 3120 degree days Celsius (Manczyk & Leach) and lasts from around September to around May. Thus it is a long period, where the polluting heat generation cause environmental impacts.

Denmark has a well developed district heating infrastructure – almost a half of heating demand is covered by district heating (cogeneration and heat only) plants. Five types of fuels are used in the district heating sector, natural gas (30%), coal (24%), waste (23%), biomass (15%) and oil (7%) (Danish Energy Authority (DEA, 2007)). Combustion of these fuels cause emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and fine particles ($PM_{2,5}$) – the prime culprit of damage on human health (European Commission (EC, 2005)).

Health effects of air pollution is a result of the sequence of several events going from emission of pollutants, atmospheric transport, dispersion and chemical transformation, leading to increase in ambient atmospheric concentrations and over the personal exposure and uptake of pollution causing the subsequent health effect (Hertel et al., 2001). Hence health related externalities depend on location of the pollution source with respect to populated areas, prevailing winds, the height of release of pollutants and the population composition – age, diseases etc. District heating in Denmark is produced in 16 centralised combined heat and power plants (CHP), 285 decentralised CHPs and 130 heat only plants (DEA, 2005). Centralised plants are typically located in the big cities and decentralised – in the smaller towns or rural communities with different proximity to densely populated areas. The recent analysis of external costs of air pollution from three typical modern cogeneration plants (burning coal, natural gas and municipal waste) in Denmark (Andersen et al, 2008) has shown the variation in these costs (Figure 1).

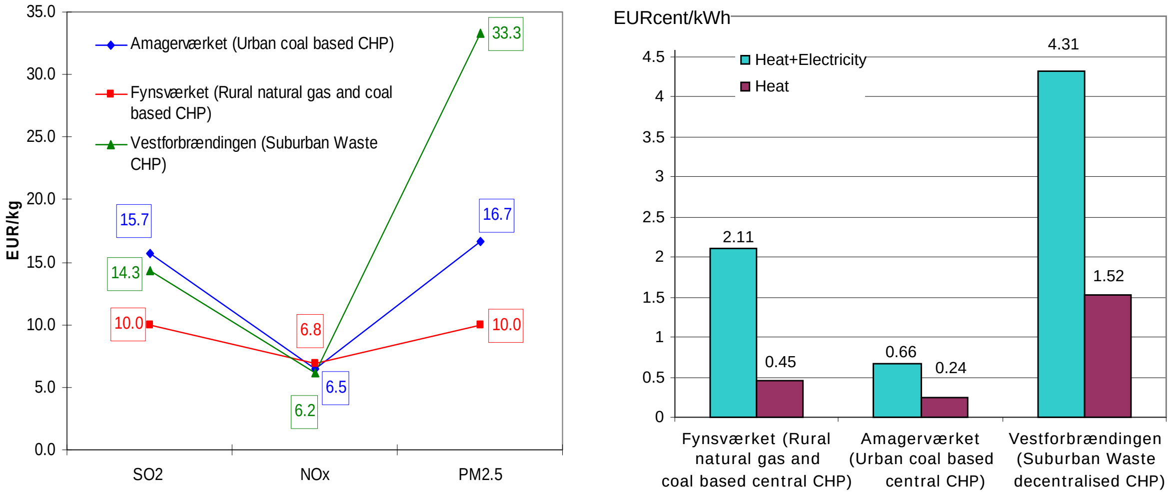

Figure 1 Health related externality costs (left – per pollution unit, right – per unit of produced electricity and heat) of three Danish CHP plants based on data from Andersen et al. (2008)

External costs per pollution unit (EUR/kg) can differ from around one an a half to three times – due to different locations of the plants with regards to populated areas, which in combination with the prevailing winds result in environmental impacts of different degree. *Fynsværket* is located in the rural area and causes the lowest environmental impact. Whereas, emissions from *Amagerværket* and *Vestforbrændingen* result in higher external costs. The location at the eastern part of Copenhagen of *Amagerværket* has some advantages as prevailing west winds transport the pollutants to the east and over the Kattegat. *Vestforbrændingen*, located west of Copenhagen causes high population exposure and consequent damage costs (especially due to exposure to fine particles) and the west winds are not advantageous in this case.

Health damage costs per unit of heat and power output can vary by around two to six times, which is the result of use of abatement technologies, fuels used, the conversion technology and its fuel efficiency. Damage costs (EUR/kg) of pollution form *Amagerværket* are higher than those of pollution from *Fynsværket* (Figure 1). Nevertheless, externalities per net energy production (EUR/kWh) are lower at the *Amagerværket*, which has installed desulphurisation and de-NO_x units. Waste incinerator has high pollution rates (due to fuel and limited abatement technologies) that cause increased pollution concentrations over large residential areas and leads to high external cost of the energy production.

According to Danish model for splitting electricity and heat production, where heat production is regarded as marginal, the greater share of emissions from a CHP is allocated to electricity production (Andersen et al., 2008). Nonetheless, external costs due to health damage from air pollution vary from 5 and up to almost 30 per cent of short term heat production cost.

The local environmental impacts of district heating production can principally be reduced by installing abatement technologies, switching to cleaner fuels, investing into cleaner heat generation technologies or by moving the polluting activities outside the populated areas. At the same time noteworthy potentials for more efficient use of energy in buildings exist. And it is widely agreed that heat savings and heat supply by district heating play essential role in reducing CO_2 emissions from heating sector in Denmark. Large heat saving potential exists in the Danish residential and public building stock, which consumes around 92 % of heat supplied by district heating (Rambøll, 2008). Around 75% of residential and public building stock with a long lifetime was constructed before end of seventies when the first important tightening of building energy standards was introduced (Tommerup & Svendsen, 2006). Tommerup and Svendsen (2006) estimate that a profitable heat saving potential is around 80 %, which can be reached over 45 years, if energy saving measures are implemented, when existing residential buildings are renovated. In the public sector estimated heat saving potential is as much as 75 % (Tommerup & Laustsen, 2008).

Reduction of heat demand by improving energy performance of buildings would reduce fuel use and by this air pollution of the heating sector. Taking into account the examination of local externality costs of three Danish cogeneration plants by Andersen et al. (2008), environmental benefits of improved energy performance of buildings and cleaner generation technologies depend on how and where heat is produced – technology, fuel and the location of the plant.

METHOD AND INPUTS

In this work the possibility for endogenous heat saving investments in buildings and local human health related external costs are included in the energy system model Balmorel. This was done in order to assess competitiveness of heat saving measures among heat generation technologies and to evaluate the possibilities to reduce local external effects from energy production, when monetary value of these effects is included into optimisation, as well as to investigate the role of heat savings in buildings.

Balmorel (www.balmorel.com) is a linear optimisation model of a power and heat system. The model is originally developed for analysis of heat and power sectors in the Baltic Sea Region (Ravn et al., 2001). Balmorel minimises operational costs of the heat and power sector by determining optimal operation of the generation units and future investments into energy production and supply infrastructure (Karlsson & Meibom, 2008). Demand for energy is given exogenously to the Balmorel and investments into energy conservation are not a part of optimisation. Thus the model is expanded by including a possibility to invest in energy performance improvements of buildings.

Important aspect for the method is, that energy models, used to analyse energy systems, with respect to local externalities, such as impacts on human health should take into account differences due to location of generation plants. In the analysis it is important to identify different DH plants and their location. Balmorel model includes identification of CHP plants (size, fuel and technology) in different DH areas and their location (e.g. urban or rural). Currently in the model distinguishes three groups of district heating areas in eastern and western Denmark – producing both heat and power (*CHP*, 19 areas), producing only heat (*DH*, 2 areas) and individual areas using oil and natural gas for heat production (*IND*, 2 areas). Furthermore, in order to reflect variations of heat saving potentials in different DH areas the location of the buildings with respect to DH areas, their age and usage are included in the model. This has been made by a GIS-based Danish Heat Atlas which maps distribution of the building stock, their heat demand and heat source as well as heat supply infrastructure in Denmark (Möller, 2008).

Literature study of heat saving potentials in buildings and the costs of different saving measures in Denmark has been made for characterising heat conservation investment options into Balmorel. The costs of four saving measures – insulating walls, roof, and floor and replacing window glass – are distinguished for buildings of different purpose and age. The heat saving potential per saving measure depends on the prevailing energy performance of buildings, which originally is defined by energy efficiency requirements at the time of construction. The current energy performance of buildings, used in the calculations, is based on data, collected during energy labelling of buildings. Consequently, the better the efficiency of a building the lower the heat saving potential and the higher cost of saved kWh of heat of an improvement measure.

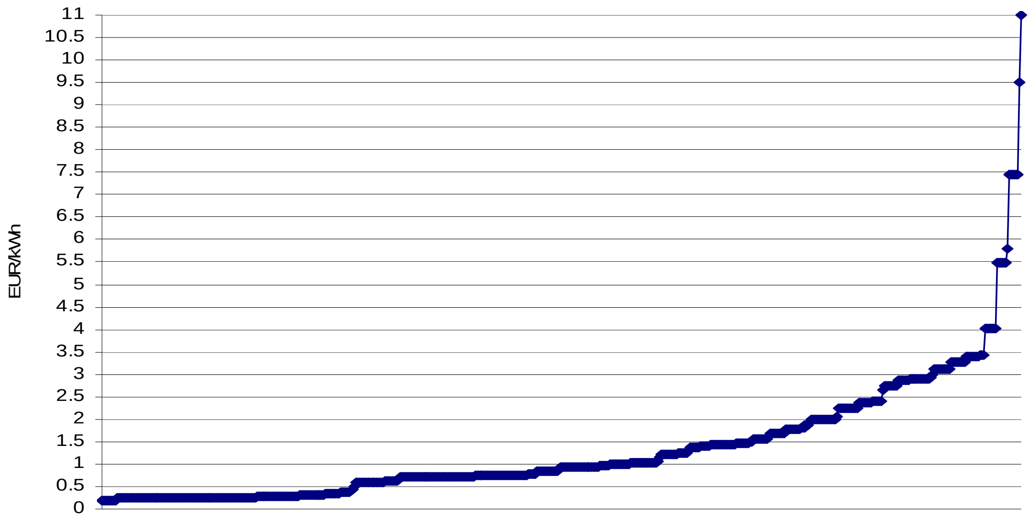

Figure 2 The distribution of costs (EUR/m^2) of heat saving measures in different building types

Figure 2 shows the distribution in heat saving measure costs for different buildings. The costs vary between 0.18 and around 11 EUR/kWh of heat saved per year. In general, replacement of windows is the dominating cheapest and insulation of walls is the dominating most expensive heat saving measure. Heats saving potential as percentage of heat demand in different heating areas are shown in Figure 3. The potential varies between around 16 % and around 34 %, and depends on the composition of building stock in different areas with respect to building type and age. The conclusion can be made, that the DK_W_Rural (rural district heating area in western Denmark) has the highest percentage of buildings with poor energy performance and the buildings with individual heating have generally the best energy performance.

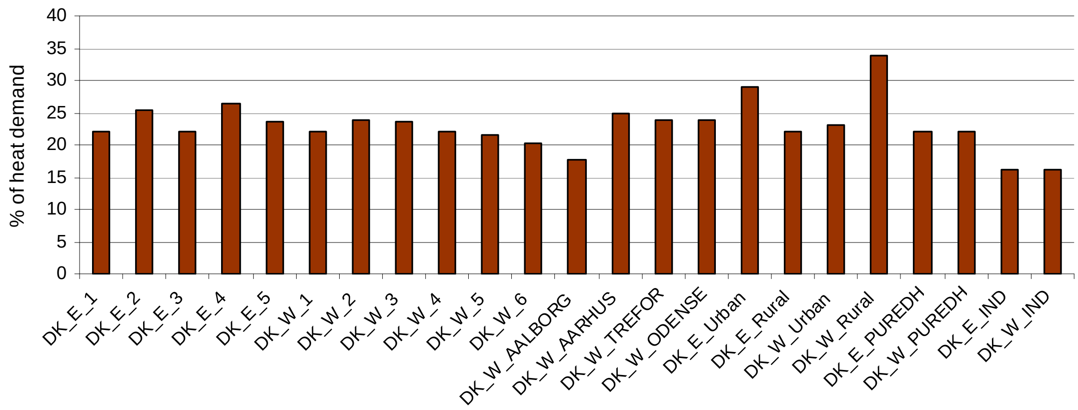

Figure 3 Heat saving potentials in different heating areas in the model

Human health related external costs have been added in the model, taking into account differences of these costs due to the localisation of heat and CHP plants with respect to the populated areas and the prevailing weather patterns (wind direction). The dominating wind in Denmark is west wind and therefore released pollutants are mainly transported to the east. The local, health related external costs, included in the model are documented in the Table 1.

Table 1 Health related external costs of pollutants taking into account localisation aspects

Area	SO_2 Cost, EUR/t	NO_x Cost EUR/t	$PM_{2,5}$ Cost EUR/t
The average cost	9100	5870	10900
The high cost	13542	10483	18533
The low cost	5962	2533	7595
The cost for individual heating	32550	9222	29200

The average external cost includes costs, related to impacts on human health, caused by the Danish energy production in the country and in other affected countries and is based on (Brandt et al, 2009). In order to include localisation aspects the variation in externality cost (high and low cost) is calculated, based on deviations from average of maximum and minimum local external costs in Spain (Linares et al.). For health related external costs, caused by pollution from individual heating devices, the local external cost for transport in used (Brandt et al, 2009). This assumption is based on Gulli (2006), who, on the basis of ExternE simulations states that it is reasonable to use the local external impacts of transport for local externality cost of distributed generation (DG).

Table 2 includes description of the scenarios for year 2025, included in the analysis.

Table 2 Scenarios modelled for year 2025

Scenario	Description
A	**No local externalities included and no heat saving investment possibilities**
B	**Local externalities included, but no heat saving investment possibilities**
C	No local externalities included, possibility to invest into heat savings in buildings
D	**Local externalities included, possibility to invest into heat savings in buildings**
D1	Local externalities included, possibility to invest into heat savings in buildings and no possibility to invest neither into solar DH nor heat pumps

The main scenarios, on which the analysis of the results is focused, are A, B and D (marked in bold in the table). In the scenarios with no local externalities, only the global CO_2 cost of 15 EUR/t is included.

RESULTS

The total local externalities of the whole Danish heat and power system and only heat production in scenarios A, B and D are calculated ex-post and compared in the Figure 4.

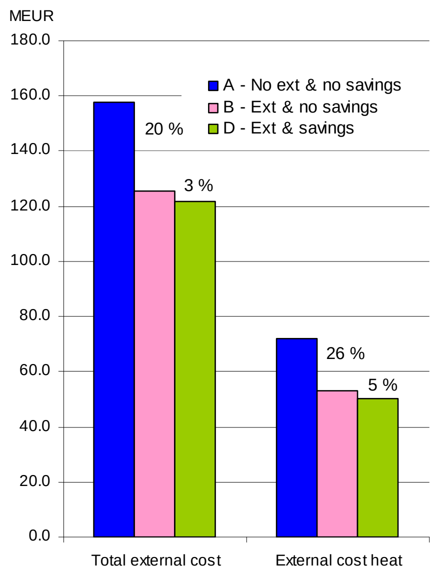

Figure 4 Total ex-post local external costs of total heat and power system and heat sector

It is evident, that inclusion of health related external costs into energy system optimisation has an effect on energy production mode and total local external costs are reduced by 20 % (reduction from scenario A to B). As it can be seen from the Figure 4 heat sector contributes considerably to local external costs from heat and power production. In scenario A, when no local externalities are included external costs from heat production contribute to around 45 % of total local external costs. This share is reduced to around 41 %, when local externalities and possibility to invest into heat savings are included (scenario D). Ex-post local external costs of heat production are reduced by 26 %, when local externalities are included. The reduction for heat sector is higher than that of the total system, and shows higher flexibility of heating sector to reduce negative impacts on human health. When possibility to invest into heat savings in buildings is introduced, health related external cost of heat production is further reduced by 5 %, which contributes to reduction of the local external cost from the total heat and power system by 3 %.

Figure 5 shows heat production by fuel in the three scenarios (A, B and D). When local externalities are included into the optimisation (scenario B) high local pollution causing biomass (wood and straw) based heat production decreases, and is replaced by less polluting natural gas and pollution-free heat production in solar and to some extent heat pump plants. Consumption of municipal waste for heat production remains unchanged, mainly due to low fuel cost. Coal based heat production is also nearly not affected, as coal is used for combined heat and power generation in the new advanced technologies with effective pollution abatement equipment.

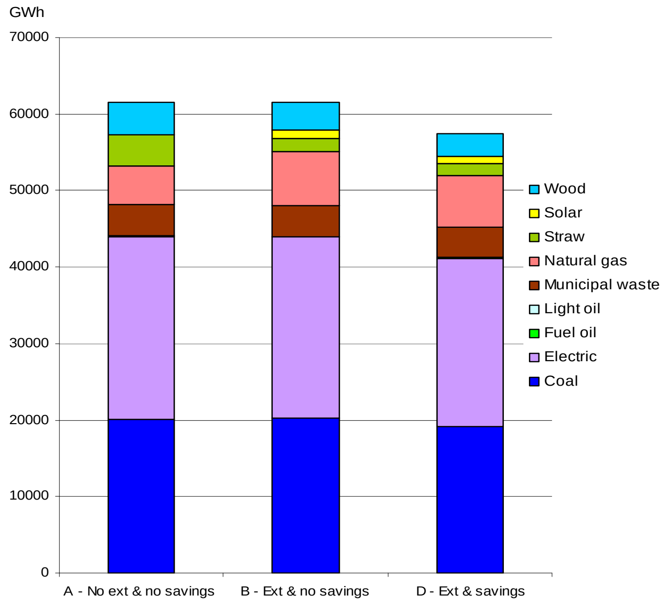

Figure 5 Heat production by fuel

In the scenario D, improvement in energy performance of buildings reduces heat production by 6.6 %. It can be noticed that heat savings replace heat production based on coal, natural gas and also slightly wood and straw when compared with scenario B. Pollution free solar and heat pump based heat production is somewhat reduced as well.

When heat saving possibilities are included into energy system optimisation model, saving measures compete with heat production technologies. Heat production in solar and heat pump plants and energy efficiency improvements of buildings are all effective measures to cut local air pollution from heating sector. In order to investigate the competition between the pollution free production and heat saving possibilities the scenario D1, where there is no possibility to invest neither into solar heating nor into heat pumps, has been calculated. The results can be seen in Figure 6, where heat saving potential utilisation in cogeneration (CHP), pure heat (DH) and individual residential heating (IND) areas is compared in scenarios D and D1. It is evident that solar heating and heat pumps compete with heat savings in cogeneration and residential heating areas.

Around 30 % heat savings would be realised in these areas, if there was no possibility to produce heat in solar and heat pump plants. In the areas with pure district heating production heat savings are not greater in the scenario D1. This can be explained by that the most economically viable heat saving potential utilisation level is at around 44 % and the further heat saving measures require much higher investments and heat production in natural gas boilers in these areas have lower costs.

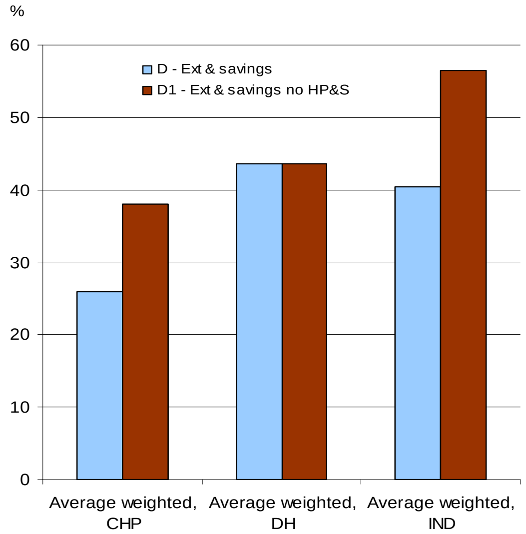

Figure 6 Average utilisation of the heat saving potential

As it can be seen in the heat saving potential in scenario D1 is least utilised in CHP areas and most utilised in individual heating areas. This can be explained by a combination of heat saving investments and their costs in different areas and the costs of heat production in different technologies in those areas. Heat production in CHP areas has lower costs (since heat is produced in combination with electricity); while heat production costs in individual heating devices are high. Furthermore, health related external costs are also highest for residential heating.

Figure 7 shows the realisation of different heat saving measures in three scenarios – when only global CO_2 cost is included (C), when also local externalities are internalised (D) and the variation of scenario D when the possibility to invest into solar and heat pump plants is excluded (D1). The investments into heat saving measures depend on effectiveness and cost of different measures, the composition of building stock and heat production mode in an area, as well as the location of the plants when local externalities are included.

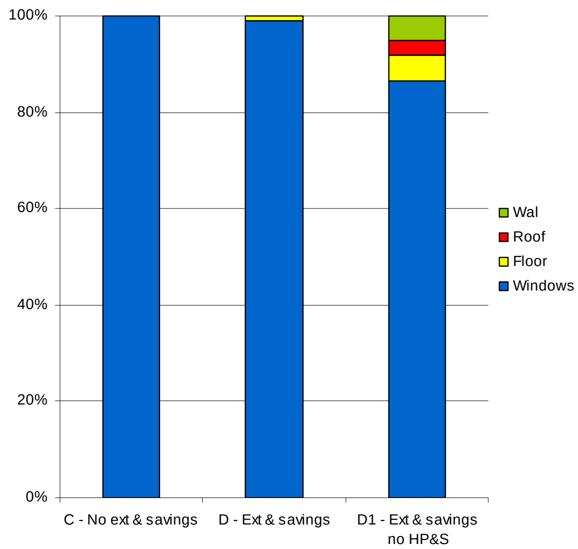

Figure 7 Realisation of different heat saving measures in buildings

From the Figure 7 it can be seen that the most economically viable, also when local externalities are not included, is replacement of window glass. When local externalities are included into optimisation, in addition to efficiency improvements of windows, floor insulation becomes economically viable in the buildings with the highest saving potentials in the areas with high local externality cost. Further, when heat pumps and solar district heating are excluded from the optimisation, the more expensive saving measures, such as roof and wall insulation are also implemented in some areas. Insulation of external walls – the most costly heat saving measure – is realised in the areas with individual residential heating.

CONCLUSIONS

The paper presented the first results of analysis of effects on heating sector when local externalities are included into optimisation. The relation between heat production, heat saving measures in buildings and health related externalities has been investigated.

The following conclusions can be drawn:

1. The preliminary results show, that when local externalities are included into energy system optimisation, the ex-post total external costs are reduced by 20 % from the whole heat and power system and by 26 % from heating sector. Energy savings reduce heat production by 6.6 % and therefore reduce health impacts from heat production by 5 %.
2. Heat saving measures compete with local emission-free heat production in solar and heat pump plants in cogeneration based district heating and heat pumps in individual residential heating areas. The results show that around 30 % of heat savings can be replaced by these local emission free technologies.
3. Heat production causes a considerable share of health related externalities from the Danish heat and power system. The analysis however has only included oil and natural gas based individual residential heating and still lacks residential

heating based on biomass (which causes high air pollution) and other fuels, as well as electric heating. Fuel consumption and emissions from wood burning stoves should also be included, since they are often used as complementary heat source, especially in individual residential heating areas.

ACKNOWLEDGEMNETS

The presented study is a part of the research of the Centre for Energy, Environment and Health, financed by The Danish Strategic Research Program on Sustainable Energy under contract no 2104-06-0027.

REFERENCES

Andersen, M.S., Frohn, L.M., Nielsen, J.S., Nielsen, M., Jensen, J.B., Jensen, S.S., Christensen, J., Brandt, J. (2008). A non-linear Eulerian approach for assessment of health cost externalities of air pollution. 16th annual conference of the European Association of Environmental and Resource Economists (EAERE), Gothenburg.

Brandt, J., Christensen, J. H., Frohn, L. M., Geels, C., Hansen, K. M., Hedegaard, G. B., Hvid, T., Hvidberg, M. and Skjøth, C. A. (2009). THOR – an operational and integrated model system for air pollution forecasting and management from regional to local scale, *7th International Conference on Air Quality - Science and Application*, Istanbul.

DEA (2007). Energy Statistics 2007. Annual Energy Statistics. Danish Energy Authority, Copenhagen. Available at www.ens.dk (accessed February 2009).

EC (2005). ExternE. Externalities of energy. Methodology 2005 update. European Commission, Luxembourg.

Hertel, O. et al. (2001). Human exposure to outdoor air pollution. Pure and Applied Chemistry 73(6), 933-958.

Karlsson, K., Meibom, P. (2008). Optimal investment paths for future renewable based energy systems – using the optimisation model Balmorel. International Journal of Hydrogen Energy 33(2008), 1777-1787.

Manczyk, H., Leach, M.D. Combined heat and power generation and district heating in Denmark: history, goals and technology. Available at www.energy.rochester.edu (accessed February 2009).

Möller, B. (2008). A heat atlas for demand and supply management in Denmark. Management of Environmental Quality: An International Journal 19(4), 467-479.

Rambøll (2008). Varmeplan Danmark (Heat Plan Denmark). Rambøll Danmark,Virum.

Ravn, H. et al. (2001). Balmorel: a model for analyses of the electricity and CHP markets in the Baltic Sea Region. Available at www.balmorel.com (accessed February 2009).

Tommerup, H., Svendsen, S. (2006). Energy savings in Danish residential building stock. Energy and Buildings 38(2006), 618-626.

Tommerup, H., Laustsen, J.B. (2008). Energibesparelser I bygninger I den offentlige sektor (Energy savings in buildings in the public sector). Danish Technical University, Kongens Lyngby.

Gulli, F., Small distributed generation versus centralised supply: a social cost-benefit analysis in the residential and service sectors, Energy Policy, 34(2006), 804-832.

Linares, P., Munoz, L., Ramos, A. and Montes, J., Internalisation of externalities into energy decision-making: A model for the social optimisation of the operation of power systems.